**EXHIBIT A**

**U.S. Patent No. 6,560,613**

US006560613B1

(12) **United States Patent**
**Gylfason et al.**

(10) **Patent No.: US 6,560,613 B1**
(45) **Date of Patent: May 6, 2003**

(54) **DISAMBIGUATING FILE DESCRIPTORS**

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(73) Assignee: **Ensim Corporation**, Sunnyvale, CA (US)

( * ) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/500,212**

(22) Filed: **Feb. 8, 2000**

(51) **Int. Cl.**[7] ..... **G06F 12/00**; G06F 17/30
(52) **U.S. Cl.** ..... **707/200**; 707/9; 707/10
(58) **Field of Search** ..... 707/9, 10, 200, 707/1, 140

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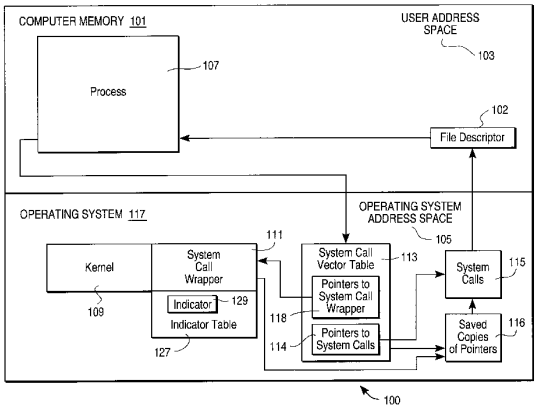
*Assistant Examiner*—Leslie Wong
(74) *Attorney, Agent, or Firm*—Fenwick & West LLP

(57) **ABSTRACT**

File descriptors associated with specific file types are disambiguated from other file descriptors by maintaining and examining an indicator table containing indicators concerning file descriptors associated with a specific, desired file type. System calls that establish a descriptor of the specific, desired type are intercepted, and an indicator concerning the established file descriptor is added to the indicator table. To keep the indicator table current, system calls that make a copy of a file descriptor or that delete a file descriptor are intercepted. If a file descriptor associated with the desired type is copied or deleted, the indicator table is updated. Therefore, the indicator table preferably includes indicators concerning all file descriptors associated with files of the specific desired type. The indicator table is examined to determine whether or not a specific file descriptor is of the desired type. In one embodiment, system calls that access files via file descriptors are intercepted, and the system call wrapper examines the indicator table to determine whether the file being accessed is of the desired type. Only if the file is of the desired type does the system call wrapper continues to execute. If the file is not of the desired type, the default system call is made. Thus, system calls that access files are selectively intercepted based upon file type.

**21 Claims, 16 Drawing Sheets**



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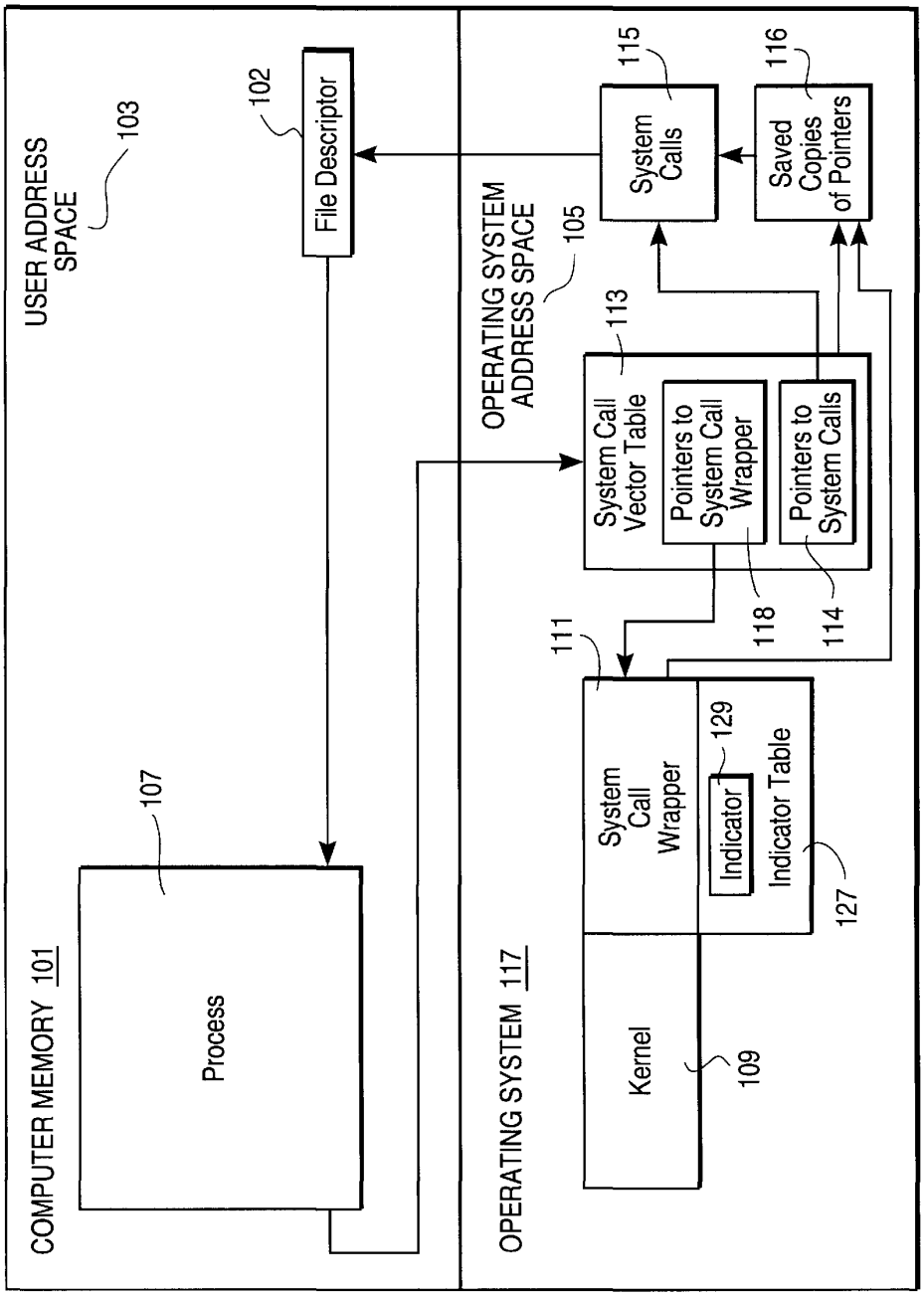
COMPUTER MEMORY 101
USER ADDRESS SPACE
103
Process
107
File Descriptor
102
OPERATING SYSTEM 117
OPERATING SYSTEM ADDRESS SPACE
105
System Calls
115
Saved Copies of Pointers
116
System Call Vector Table
113
Pointers to System Call Wrapper
Pointers to System Calls
118
114
111
System Call Wrapper
129
Indicator
Indicator Table
127
Kernel
109
100

FIG. 1

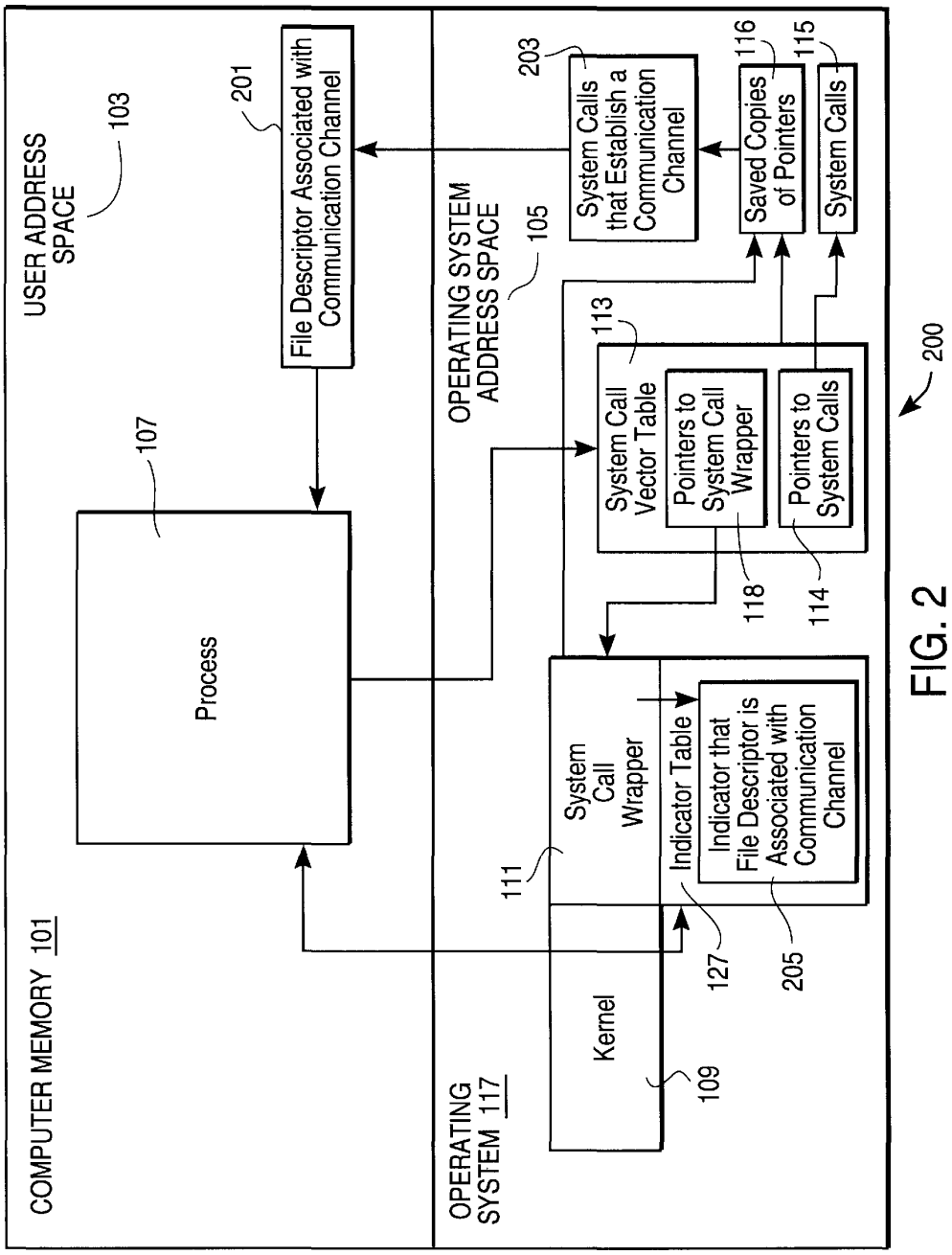
COMPUTER MEMORY 101
USER ADDRESS SPACE
103
Process
107
File Descriptor Associated with Communication Channel
201
OPERATING SYSTEM 117
OPERATING SYSTEM ADDRESS SPACE
105
Kernel
109
System Call Wrapper
111
System Call Vector Table
113
Pointers to System Call Wrapper
Pointers to System Calls
Indicator Table
Indicator that File Descriptor is Associated with Communication Channel
127
205
118
114
System Calls that Establish a Communication Channel
203
Saved Copies of Pointers
116
System Calls
115
200

FIG. 2

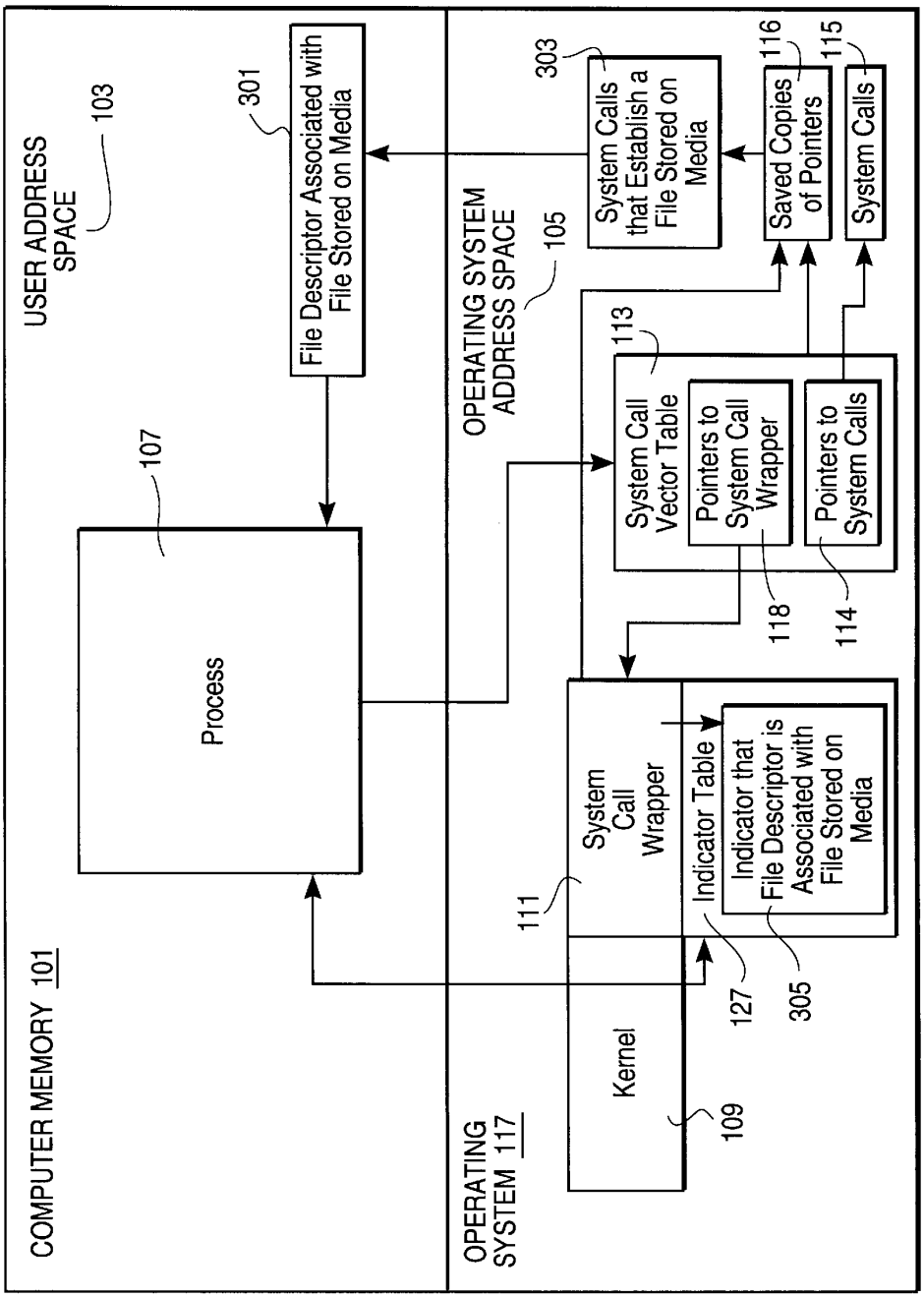
COMPUTER MEMORY 101
USER ADDRESS SPACE
103
Process
107
File Descriptor Associated with File Stored on Media
301
OPERATING SYSTEM ADDRESS SPACE
105
System Calls that Establish a File Stored on Media
303
Saved Copies of Pointers
116
System Calls
115
System Call Vector Table
113
Pointers to System Call Wrapper
118
Pointers to System Calls
114
300
System Call Wrapper
111
Indicator Table
127
Indicator that File Descriptor is Associated with File Stored on Media
305
OPERATING SYSTEM 117
Kernel
109

FIG. 3

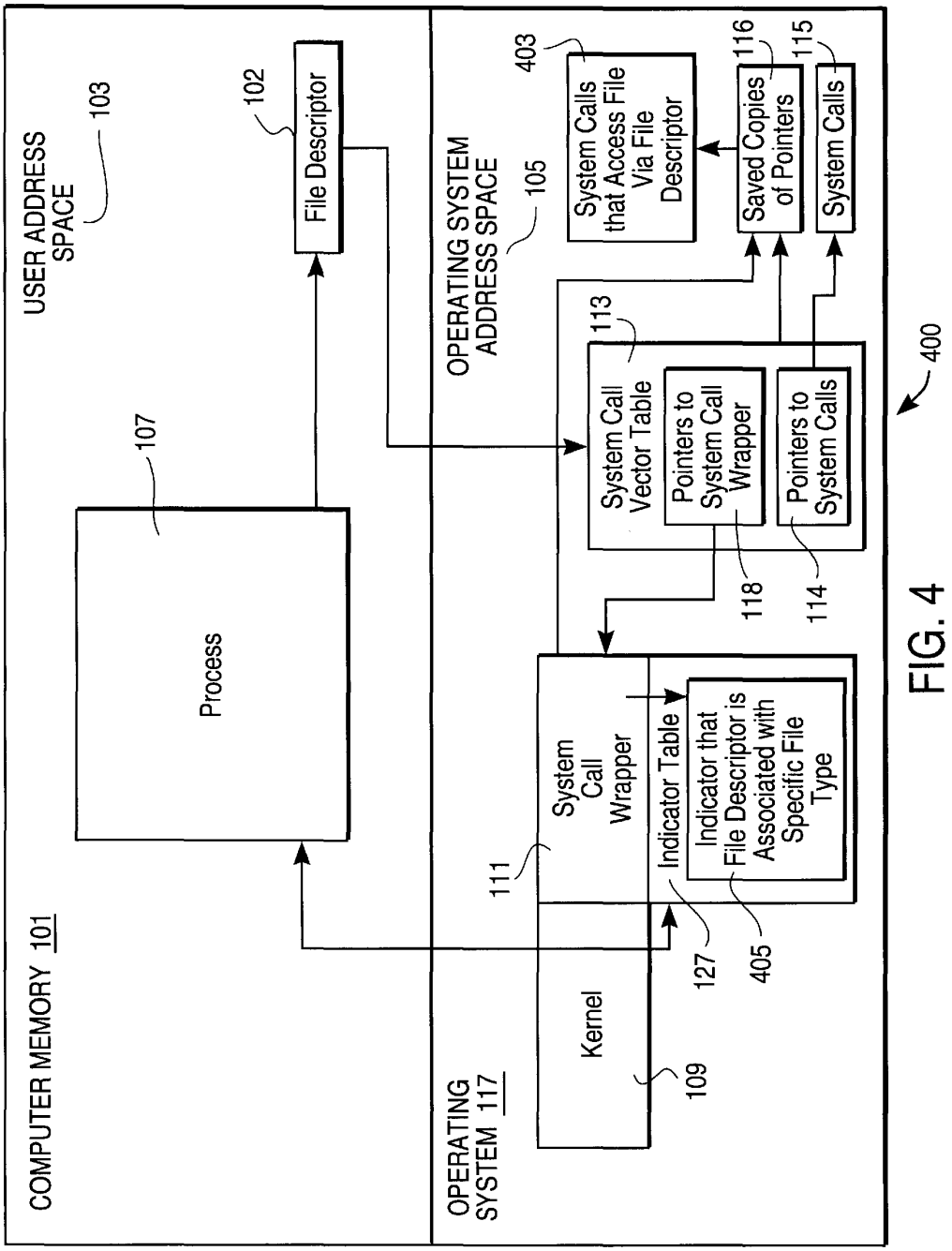
COMPUTER MEMORY 101
USER ADDRESS SPACE
103
File Descriptor
102
Process
107
OPERATING SYSTEM 117
OPERATING SYSTEM ADDRESS SPACE
105
System Calls that Access File Via File Descriptor
403
Saved Copies of Pointers
116
System Calls
115
System Call Vector Table
113
Pointers to System Call Wrapper
Pointers to System Calls
118
114
400
System Call Wrapper
111
Indicator Table
Indicator that File Descriptor is Associated with Specific File Type
127
405
Kernel
109

FIG. 4

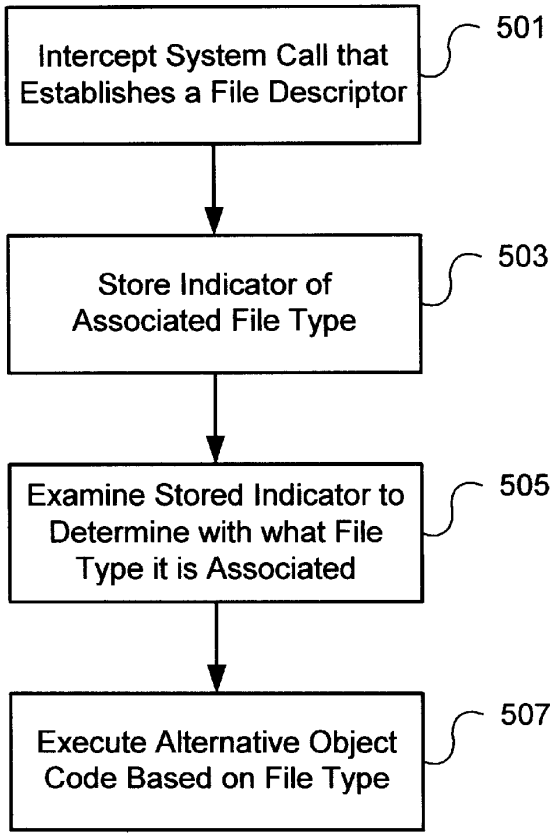
Intercept System Call that Establishes a File Descriptor
501
Store Indicator of Associated File Type
503
Examine Stored Indicator to Determine with what File Type it is Associated
505
Execute Alternative Object Code Based on File Type
507

FIG. 5A

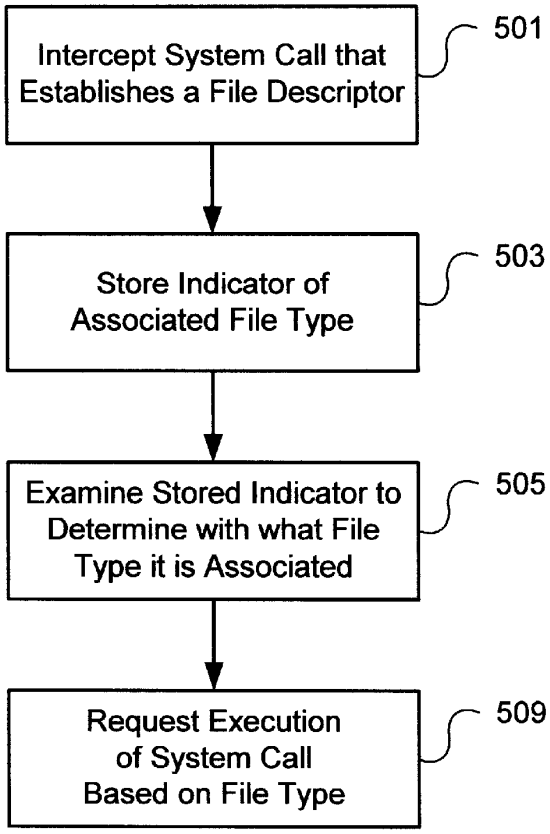
Intercept System Call that Establishes a File Descriptor
501
Store Indicator of Associated File Type
503
Examine Stored Indicator to Determine with what File Type it is Associated
505
Request Execution of System Call Based on File Type
509

FIG. 5B

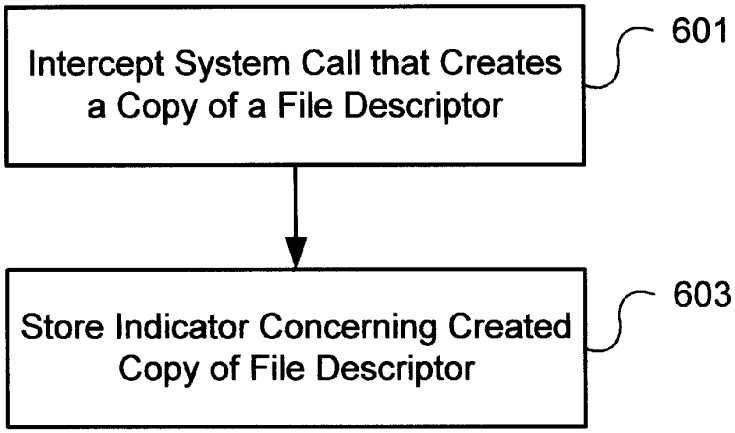
Intercept System Call that Creates a Copy of a File Descriptor
601
Store Indicator Concerning Created Copy of File Descriptor
603

FIG. 6A

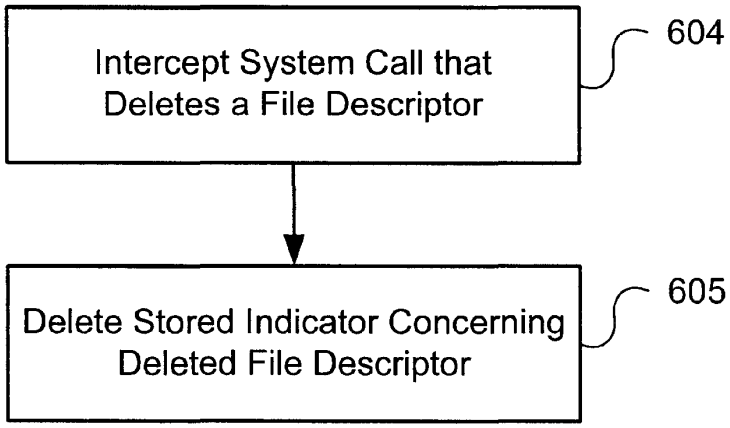
Intercept System Call that Deletes a File Descriptor
604
Delete Stored Indicator Concerning Deleted File Descriptor
605

FIG. 6B

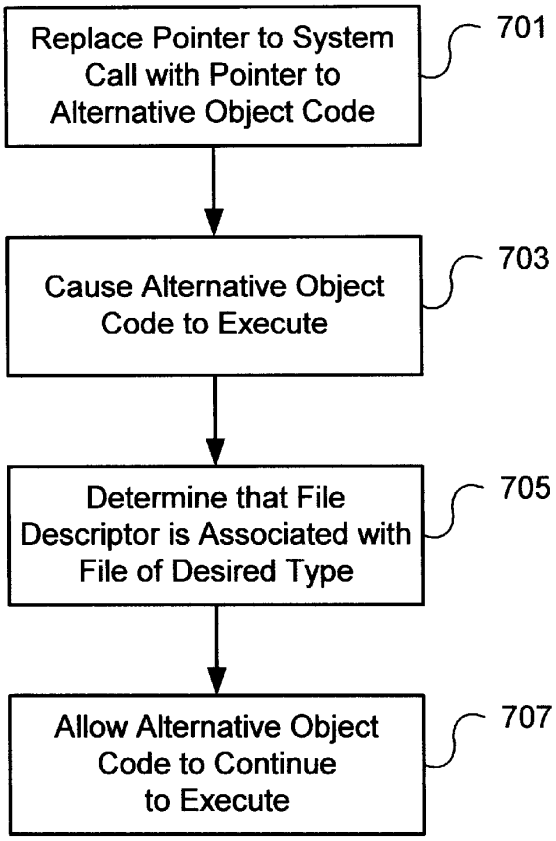
Replace Pointer to System Call with Pointer to Alternative Object Code
701
Cause Alternative Object Code to Execute
703
Determine that File Descriptor is Associated with File of Desired Type
705
Allow Alternative Object Code to Continue to Execute
707

FIG. 7A

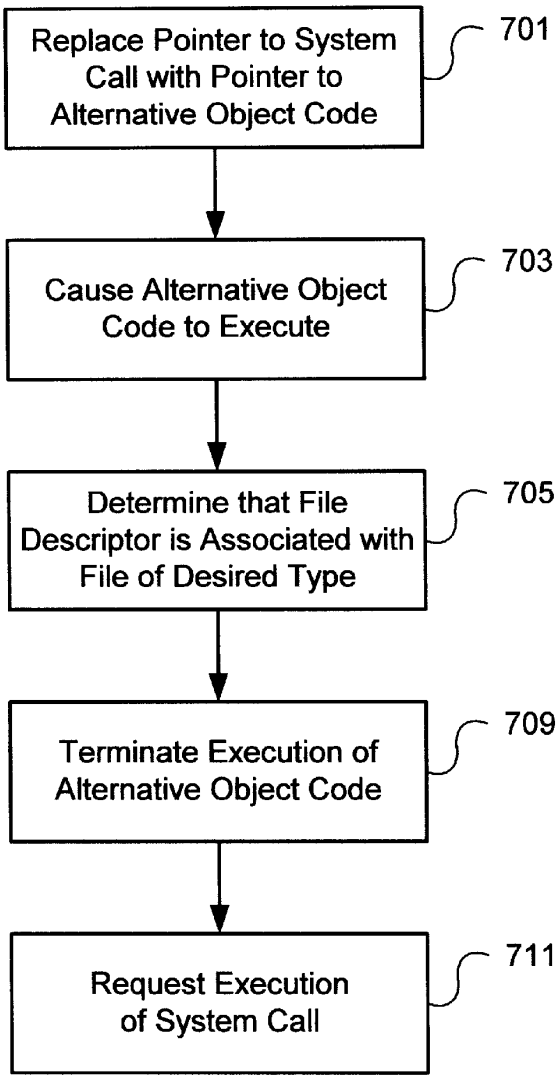
Replace Pointer to System Call with Pointer to Alternative Object Code
701
Cause Alternative Object Code to Execute
703
Determine that File Descriptor is Associated with File of Desired Type
705
Terminate Execution of Alternative Object Code
709
Request Execution of System Call
711

FIG. 7B

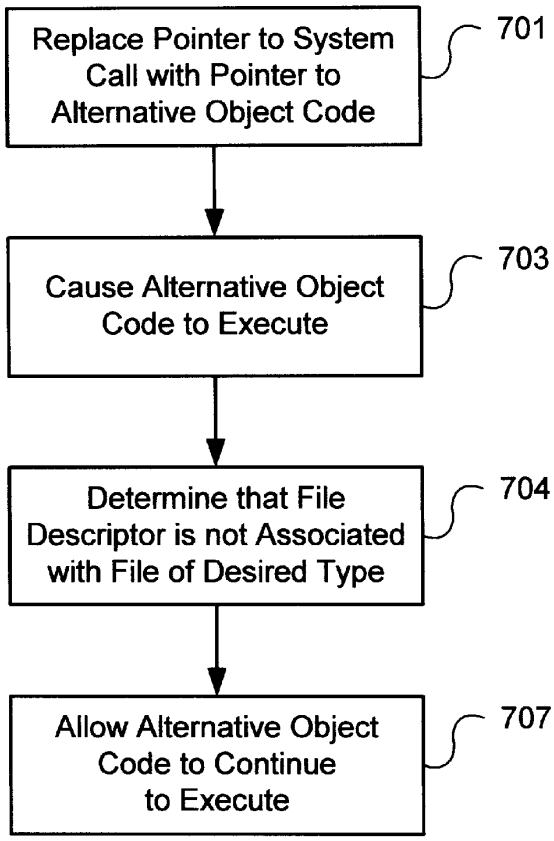
Replace Pointer to System Call with Pointer to Alternative Object Code
701
Cause Alternative Object Code to Execute
703
Determine that File Descriptor is not Associated with File of Desired Type
704
Allow Alternative Object Code to Continue to Execute
707

FIG. 7C

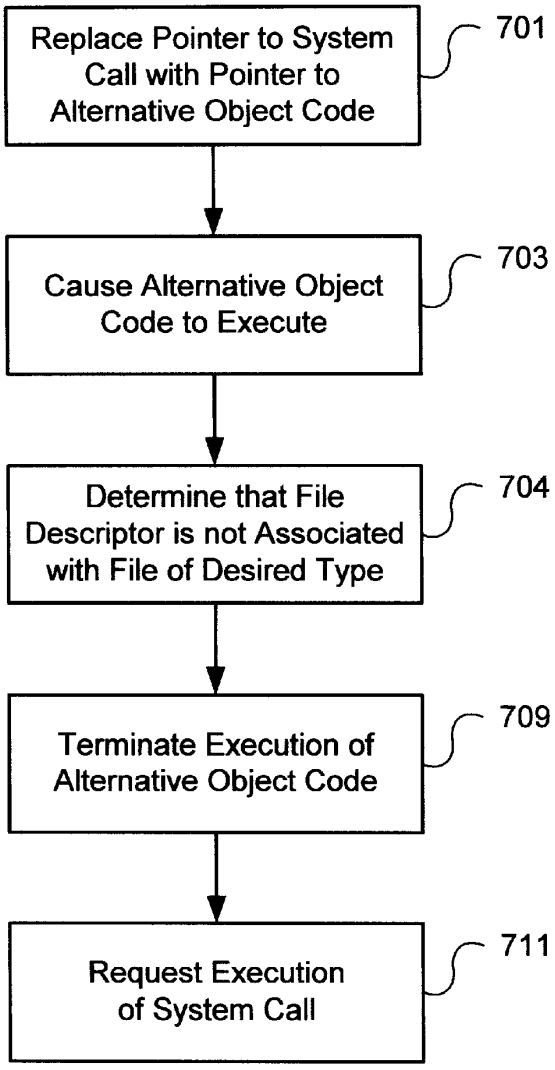
Replace Pointer to System Call with Pointer to Alternative Object Code
701
Cause Alternative Object Code to Execute
703
Determine that File Descriptor is not Associated with File of Desired Type
704
Terminate Execution of Alternative Object Code
709
Request Execution of System Call
711

FIG. 7D

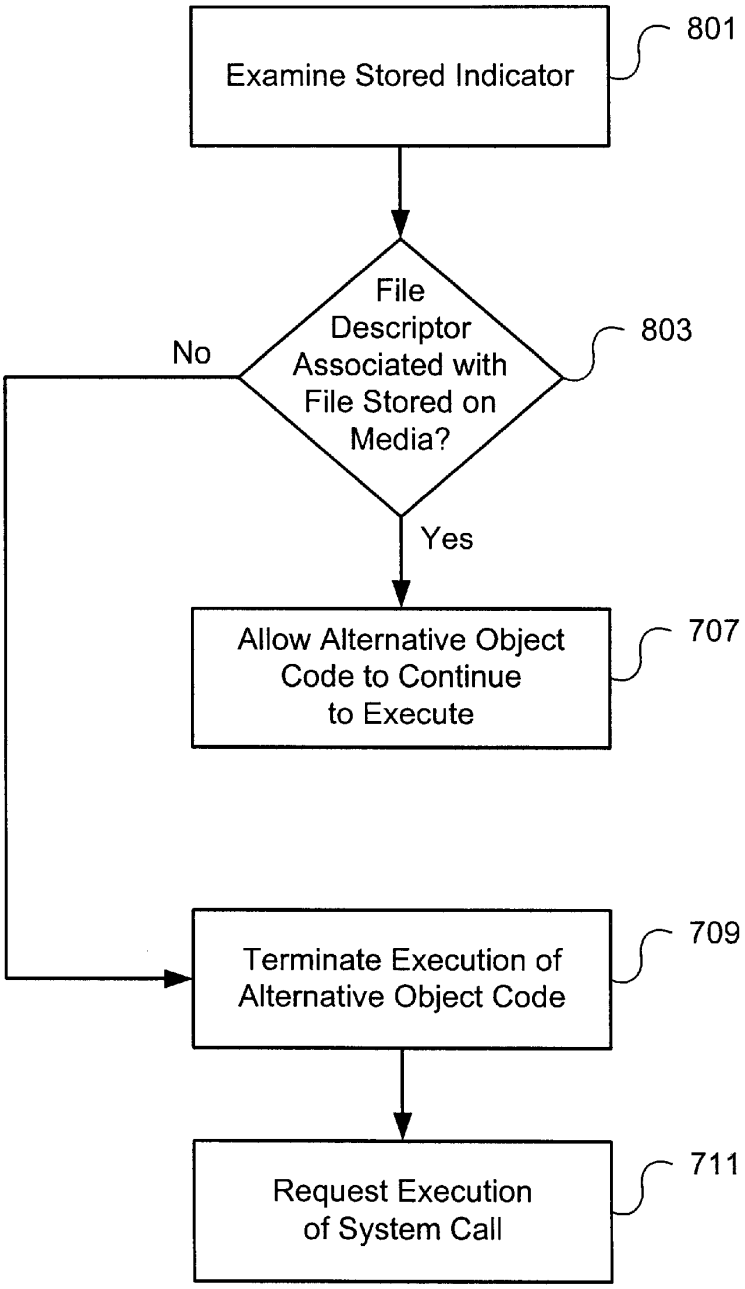
Examine Stored Indicator
801
File Descriptor Associated with File Stored on Media?
803
No
Yes
Allow Alternative Object Code to Continue to Execute
707
Terminate Execution of Alternative Object Code
709
Request Execution of System Call
711

FIG. 8A

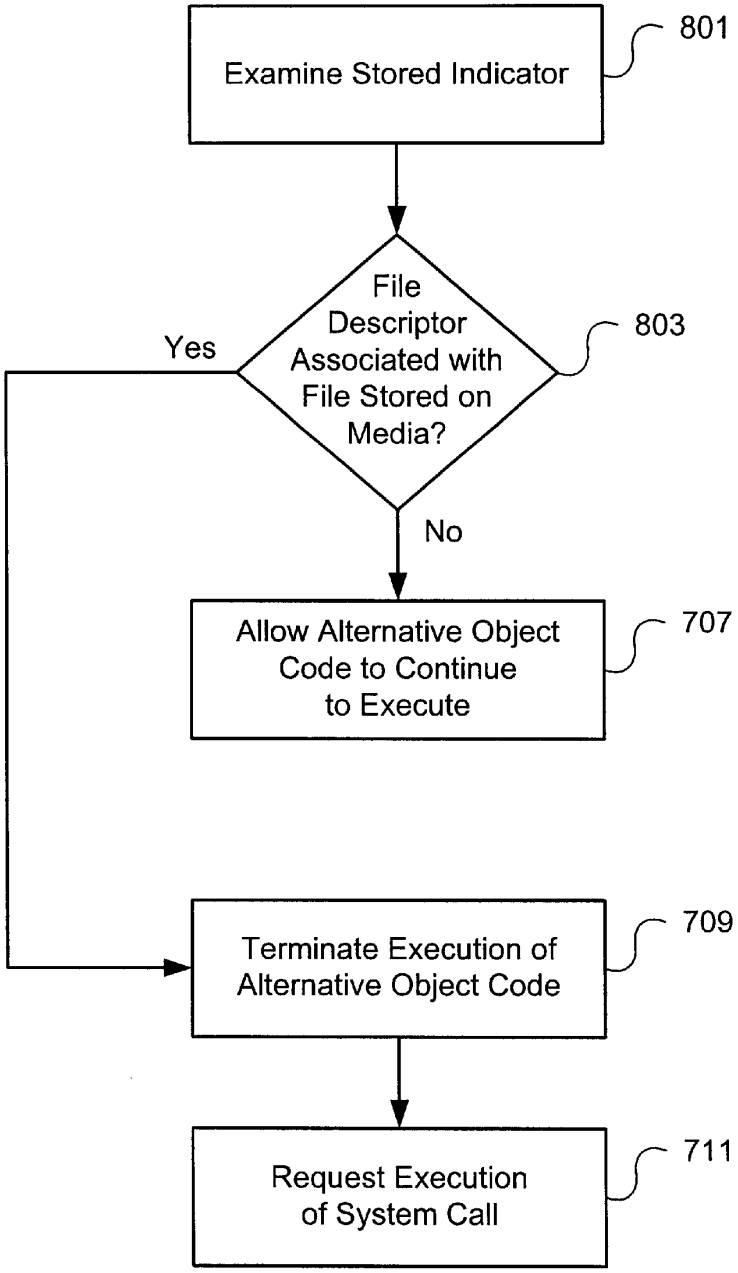
Examine Stored Indicator
801
File Descriptor Associated with File Stored on Media?
803
Yes
No
Allow Alternative Object Code to Continue to Execute
707
Terminate Execution of Alternative Object Code
709
Request Execution of System Call
711

FIG. 8B

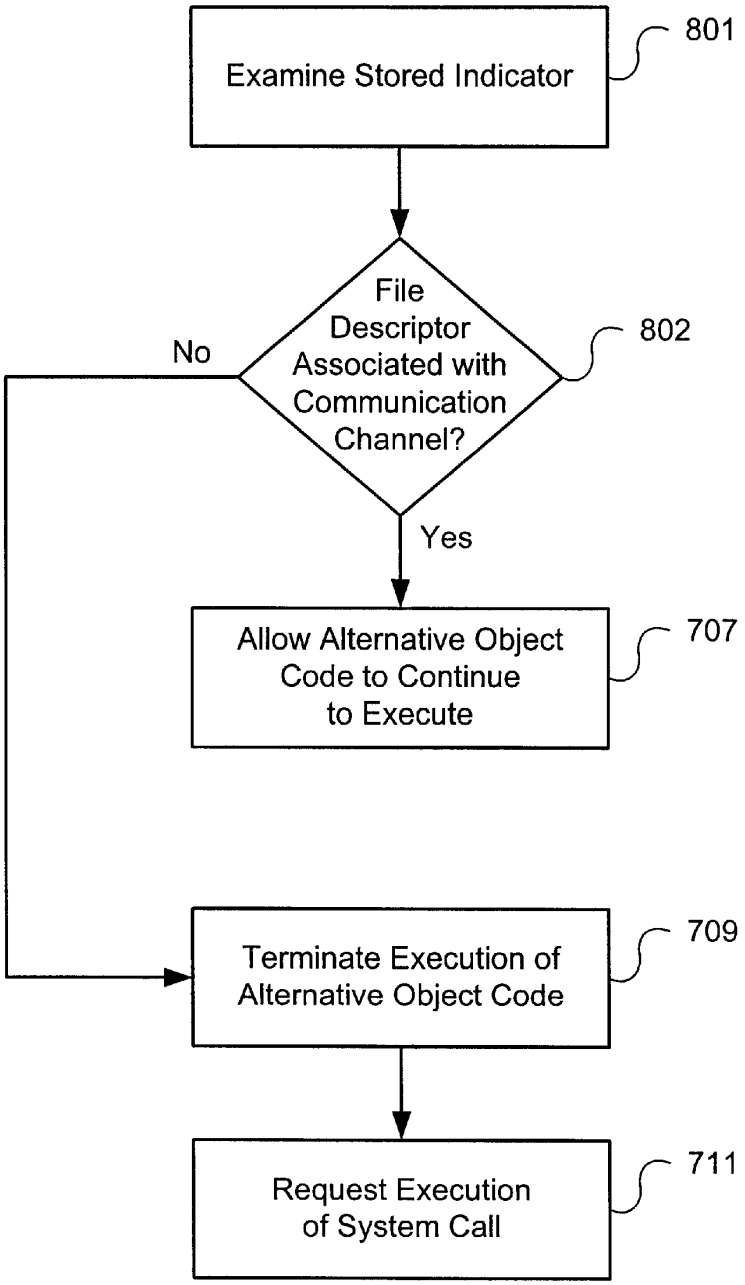
Examine Stored Indicator
801
File Descriptor Associated with Communication Channel?
802
No
Yes
Allow Alternative Object Code to Continue to Execute
707
Terminate Execution of Alternative Object Code
709
Request Execution of System Call
711

FIG. 8C

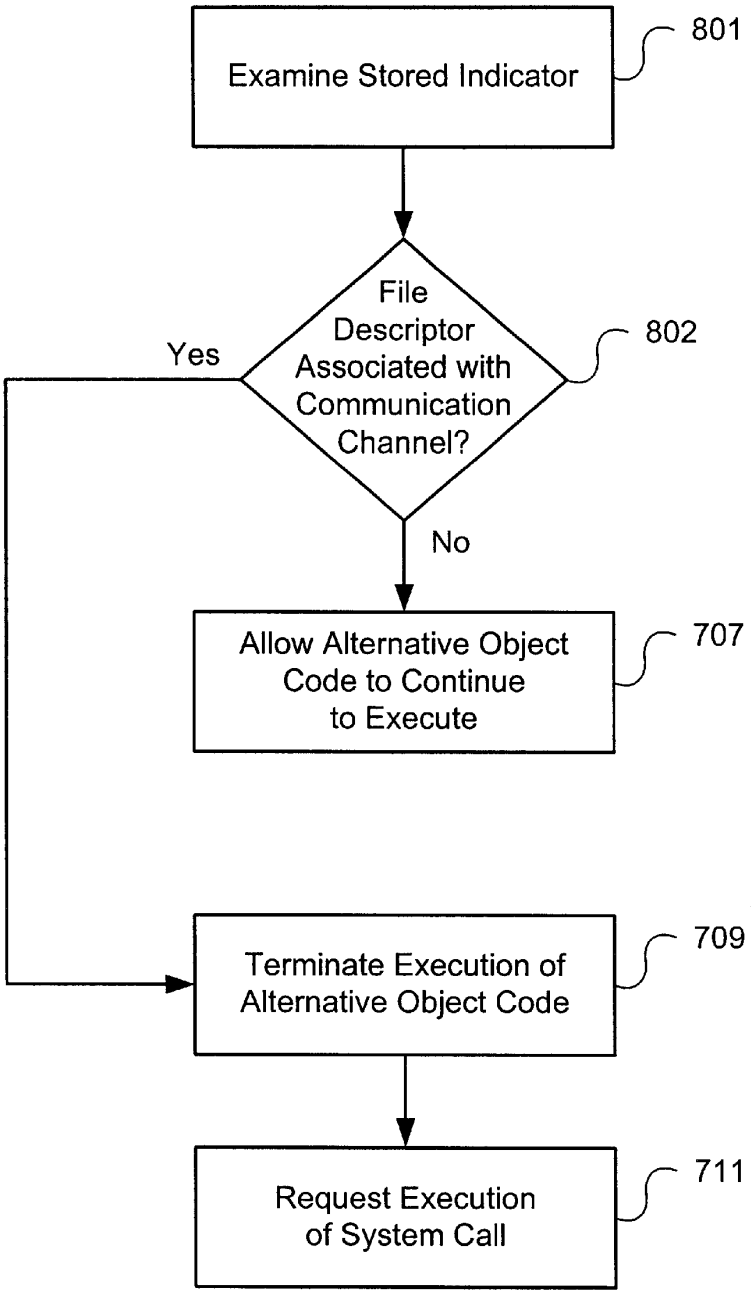
Examine Stored Indicator
801
File Descriptor Associated with Communication Channel?
802
Yes
No
Allow Alternative Object Code to Continue to Execute
707
Terminate Execution of Alternative Object Code
709
Request Execution of System Call
711

FIG. 8D

# DISAMBIGUATING FILE DESCRIPTORS

## BACKGROUND

### Field of Invention

The present invention relates generally to disambiguating file types on a computer system, and specifically to disambiguating communication channel file descriptors from file descriptors that that are associated with files stored on physical media.

## BACKGROUND OF INVENTION

Operating systems such as UNIX® and Microsoft WINDOWS NT® are widely utilized in commercial computing systems. Among their many commercial uses, these operating systems are commonly deployed on Internet and other network server computers. With the popularity and success of the Internet, server computer operating systems are currently of great commercial importance.

Frequently, it is desirable to intercept system calls that pertain to accessing files. Although operating systems include various internal resources for accessing a file system, it is often desirable to customize or extend operating system functionality for a particular use. Such customization allows a computer programmer, a network administrator, or a webmaster to utilize the operating system in a specific manner beyond the default system capabilities provided by the manufacturer of the operating system. The interception of system calls is one such method of extending and expanding operating system functionality.

A system call is a subroutine, the object code of which is located in an operating system, such that the subroutine can be called by processes executing under the control of the operating system. When executed, a system call performs some system operation, such as the access of a system hardware or software resource. Examples of operations executed by system calls include reading data from a file, opening a network communication channel, and allocating computer memory to a specific process. Application programs (processes) executing under the control of the operating system make a system call in order to bring about the performance of these and other system operations.

System calls are accessed by the operating system, using a system call vector table. A system call vector table is an area in operating system address space. A system call vector table stores pointers to the actual executable code of the system calls. In order to make a system call, arguments are programmatically loaded into specific registers of the central processing unit of the computer on which the operating system is executing. One of these arguments identifies the specific system call that is being made. This argument is typically in the form of a number that is an offset into the system call vector table. The other loaded arguments include parameters to be passed to the system call.

Once the arguments have been loaded, a software interrupt is generated, signaling to the operating system that a process is requesting execution of a system call. The operating system reads the registers, and executes the requested system call with the specified parameters. The system call executes and performs the desired functionality. If the system call generates a return value, it places the generated return value (or a pointer thereto) in a pre-designated register where it can be accessed by the calling process.

In order to intercept a system call, a pointer in the system call vector table to the system call is replaced with a pointer to alternative object code to be executed instead of the system call. Then, when the operating system reads the system call vector table in response to the system call being requested, the operating system will read the pointer to the alternative object code, and the alternative object code will execute instead of the system call. The alternative object code is typically known as a system call wrapper.



The interception of system calls providing access to the file system is useful to extend and customize operating system functionality. For example, the interception of system calls can be used to manipulate operating system access privileges to provide security beyond that which is provided by the operating system. Through the interception of system calls that provide access to the file system, processes can be prevented from deleting, modifying, creating, or even reading files. This is desirable, for example, when a user wishes to remotely execute a program residing on a web server, but does not want the remote program to be able to read or alter private data on the user's computer. Today, Java applets are commonly employed to provide such security. However, many programs that users wish to remotely execute are written in languages other than Java. System call interception has the potential to allow the safe execution of programs written in all languages.

The interception of system calls is known today, although it is an advanced systems programming technique. Nonetheless, a serious shortcoming limits the usefulness of intercepting system calls that provide access to the file system. That shortcoming is the inability to disambiguate between a file descriptor that is associated with a file stored on media (e.g. hard disk, optical disk, random access memory) and a file descriptor that is associated with a communication channel.

Many computer operating systems utilize file descriptors to provide access to file systems. Under such operating systems, a file is created by making a system call that creates a file and returns a file descriptor that is associated with the newly created file. Subsequently, the file is accessed via the file descriptor. Examples of file access operations include reading from a file, writing to a file, closing a file, and deleting a file. Such operations are typically conducted by making a designated system call, and passing the system call the file descriptor that is associated with the file being accessed.

Many commercially popular operating systems such as UNIX® and Microsoft WINDOWS NT® treat communication channels as files. In such an operating system, when a process makes a system call in order to establish a communication channel, the operating system returns a file descriptor. The communication channel is subsequently accessed via the file descriptor, in a similar manner as a file stored on media.

Commonly, the same system calls are made to perform the same access operations on both files stored on media and on communication channels. For example, under the UNIX® operating system, a read system call can be made in order to read data from either a file stored on media or from a communication channel. The system call itself has no information concerning with what file type a file descriptor is associated, that is whether the file descriptor refers to a communication channel or a file stored on media. The system call simply executes instructions to access a file in a specific manner via a file descriptor. For example, the read system call executes instructions to copy a specific number of bytes from a file to a buffer in memory. The read system call does not distinguish between a file on media and a

communication channel, and in fact has no indication concerning from what file type it is reading data.

Because the system calls that access files via file descriptors do not distinguish between a file on media and a communication channel, a system call wrapper that executes when such a system call is intercepted has no mechanism for so distinguishing. For example, if the read system call is intercepted, the system call wrapper will execute whenever any process makes the system call to read data from any type of file. Thus, the system call wrapper will execute whenever a process attempts to read data from a file stored on media and also whenever a process attempts to read data from a communication channel.

Communication channels and files stored on media are inherently different, despite the fact that both are accessed via file descriptors. It is often desirable to intercept system calls that access a file stored on media, but not to intercept system calls that access a communication channel. Likewise, it is often desirable to intercept system calls that access a communication channel, but not to intercept system calls that access a file stored on media. Specifically, in the example given above concerning intercepting system calls to prevent processes from manipulating files, it is desirable only to intercept system calls that access files stored on media. The desired result is to prevent access to files stored on media, but not to prevent access to communication channels. For example, it may be desirable to prevent write access to the file system of a specific client computer. At the same time, it may be undesirable to prevent write access to the communication channels of the client computer, because it would be desirable for the computer to be able to receive communication responses from web servers. However, intercepting every write system call and executing a system call wrapper in its place to prevent write access would prevent write access to both communication channels and to files stored on media.

Likewise, it is often desirable to intercept system calls that pertain to access of communication channels, but not to intercept system calls that pertain to access of files stored on media. For example, it may be desirable to disallow remote communication requests made to a certain computer, but at the same time desirable to allow local access to files stored on media of the computer. Again, because the same system call is used to access communication channels and files stored on media, the one can not be prevented and yet the other allowed.

It is further desirable to be able to disambiguate file descriptors generally. Under some operating systems, entities other than communication channels and files stored on media are treated as files, and hence accessed via file descriptors. For example, under the UNIX® operating system, hardware devices are designated by file descriptors. For the same reasons that it is desirable to disambiguate communication channel file descriptors from file descriptors that are associated with files stored on media, it is further desirable to be able to disambiguate file descriptors that are associated with any type of file from those that are associated with any other type.

Accordingly, what is needed is a method to disambiguate file descriptors generally, and specifically to disambiguate file descriptors that that are associated with files stored on media from file descriptors that that are associated with communication channels. This would allow for the selective interception of system calls that access one type of file or another.

## SUMMARY OF INVENTION

The present invention allows disambiguation of file descriptors generally, and disambiguation of communication channel file descriptors from file descriptors that are associated with files stored on media specifically. In order to so disambiguate, indicators concerning file descriptors that are associated with a specific file type are stored. When file descriptors are subsequently utilized to access files, the indicators are examined in order to determine the associated file type.

In one preferred embodiment, the indicators concerning communication channel file descriptors are stored in an indicator table. In order to maintain the table, system calls that establish a communication channel are intercepted. Pointers in the system call vector table to system calls that establish a communication channel are replaced with pointers to alternative object code (a system call wrapper), such that when the system calls are made, the system call wrapper executes instead. The system call wrapper first executes the system call, to allow the communication channel to be established. The system call wrapper then stores an indicator that the file descriptor returned by the system call is associated with a communication channel. Preferably, this indicator is stored in a table in operating system address space. In alternative embodiments indicators are stored in other data structures (for example a linked list) in either operating system address space or user address space as desired.

In order to keep the table complete, in one embodiment system calls that copy a file, copy a file descriptor, or copy an entire file descriptor table are intercepted. As with the interception of system calls that establish a communication channel, pointers in the system call vector table to system calls to be intercepted are replaced with pointers to a system call wrapper. The system call wrapper checks the stored indicators to determine whether any file descriptors to be copied are associated with a communication channel. If so, the system call wrapper first executes the system call, to allow the copy to be created. The system call wrapper then stores, for each created copy of a file descriptor that is associated with a communication channel, an indicator that the copy of the file descriptor is associated with a communication channel. If no file or file descriptor to be copied is associated with a communication channel, the system call wrapper simply makes the system call such that execution control returns to the calling process after the system call executes.

Additionally, in order to keep the table current, in one embodiment system calls that delete file descriptors are intercepted. Again, pointers in the system call vector table to system calls that delete file descriptors are replaced with pointers to a system call wrapper. The system call wrapper checks the stored indicators to determine whether a file descriptor to be deleted is associated with a communication channel. If so, the system call wrapper first executes the system call, to allow the file descriptor to be deleted. The system call wrapper then deletes the indicator that the file descriptor is associated with a communication channel. This is desirable because the file descriptor no longer exists, so the association is no longer accurate or relevant. If no file descriptor to be deleted is associated with a communication channel, the system call wrapper simply makes the system call such that execution control returns to the calling process after the system call executes.

To summarize, system calls that create a communication channel are intercepted, as are system calls that either copy or delete existing file descriptors. The system call wrapper that executes when these system calls are intercepted maintains a table of stored indicators concerning communication channel file descriptors. Thus, the table preferably includes an indicator for every existing communication channel file

descriptor. The stored indicators can subsequently be examined by any process to disambiguate file descriptors. For example, because communication channel file descriptors are indicated in the table, any process can examine the table to determine whether or not a given file descriptor is a communication channel file descriptor. In an operating system in which every file descriptor either is a communication channel file descriptor or a descriptor of a file stored on media, the table of indicators concerning file descriptors can also be examined to determine if a given file descriptor is associated with a file stored on media. This is true because if the table does not contain an indicator for a given file descriptor, that file descriptor is not a communication channel file descriptor, and therefore is a descriptor of a file stored on media.

In another preferred embodiment of the present invention, system calls that create a file that is stored on media are intercepted, as opposed to system calls that establish a communication channel. Thus, the table of indicators comprises indicators of file descriptors that are associated with files stored on media. As with the previously described embodiment, system calls that copy or delete file descriptors are also intercepted, and an indicator table is maintained. The indicator table is then examined to determine whether or not a file descriptor is associated with a file stored on media.

Because the present invention allows any process to disambiguate file descriptors, the present invention can be utilized to selectively intercept system calls that access a file stored on media. Likewise, the present invention can be utilized to selectively intercept system calls that access a communication channel.

In order to selectively intercept system calls that access files, system calls that access a file via a file descriptor are initially intercepted. The system call wrapper that executes when such system calls are intercepted proceeds to examine the stored indicator table to determine the type of file with which the file descriptor is associated. If the file descriptor is associated with a desired file type, the system call wrapper continues to execute. Otherwise, the default system call is made and then execution control returns to the calling process.

For example, suppose it is desirable only to intercept system calls that pertain to communication channels, but not to intercept system calls that pertain to files stored on media. When a read system call is made, the system call wrapper examines the indicator table to determine whether the file descriptor from which the system call is to read data is associated with a communication channel. If so, the system call wrapper proceeds to execute as desired. If the file descriptor is not associated with a communication channel, the default system call is executed, such that execution control is returned to the calling process after the system call terminates.

It will be readily apparent to one skilled in the art that the present invention can be utilized to disambiguate any type of file descriptor. Thus, although disambiguating communication channel file descriptors from file descriptors that are associated with files stored on media is one function of the present invention, the present invention is by no means so limited. For example, the UNIX® operating system treats hardware devices as files, as noted above. Under UNIX®, the present invention can be utilized to create and maintain an indicator table concerning hardware device file descriptors. Then, the indicator table can be utilized to disambiguate hardware device file descriptors from other kinds.

It is to be understood that disambiguation by file type can be conducted at varying levels of specificity (in other words, the term "file type" can be defined as broadly or narrowly as desired). For example, in one embodiment file descriptors that are associated with files stored on media are disambiguated from communication channel file descriptors, as described above. In another embodiment, file descriptors that are associated with files stored on media in a specific directory are disambiguated from files descriptors that are associated with other files stored on media. In yet another embodiment, file descriptors concerning files with specific attributes, such as system or read-only, are disambiguated from file descriptors concerning files without those attributes. In fact, files descriptors concerning a specific file can even be disambiguated from all other file descriptors.

It will also be apparent that the present invention can be utilized to disambiguate file descriptors by any process. Although file descriptor disambiguation by a system call wrapper to allow for selective system call interception is an embodiment of the present invention, it is by no means the only embodiment. The examination of the indicator table by any process for the purpose of file descriptor disambiguation is within the scope of the present invention. For example, suppose a user process executing on a web server has permission to write to communication channels of the server in order to make communication requests, but does not have permission to write to the file system of the web server. It would be both desirable and within the scope of the present invention for the process to examine the indicator table to determine if a specific file descriptor is or is not associated with a communication channel.

Further, one skilled in the art will readily comprehend that many combinations of indicator storage and examination to disambiguate file descriptors are possible. All such combinations are within the scope of the present invention. For example, to make a binary distinction between two types of file descriptors (for example, communication channel file descriptors and those that are associated with files stored on media), indicators concerning either type of file descriptor may be stored and examined to is determine if any file descriptor on the system is of one type or the other. If the indicator table comprises indicators concerning communication channel file descriptors, the table could be examined to determine if any given file descriptor is associated with a communication channel, or to determine if the file descriptor is associated with a file stored on media. Likewise, if the indicator table comprises indicators concerning file descriptors that are associated with files stored on media, the table could be examined to determine if any given file descriptor is associated with a file stored on media, or to determine if the file descriptor is associated with a communication channel.

Under an operating system that allows more than two types of file descriptors (for example, communication channel file descriptors, file descriptors that are associated with files stored on media, and hardware device file descriptors), an indicator table concerning any given file descriptor type can be maintained and subsequently examined to determine if a specific file descriptor is or is not associated with a file of the given type. Alternatively, an indicator table concerning multiple file descriptor types (or multiple indicator tables each concerning one or more types) could be maintained and examined to disambiguate file descriptors. All such embodiments are within the scope of the present invention.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a high level block diagram illustrating a system for disambiguating file descriptors according to one embodiment of the present invention.

FIG. **2** is a block diagram illustrating a system for maintaining and utilizing an indicator table in order to disambiguate file descriptors that are associated with communication channels from those that are not, according to one embodiment of the present invention.

FIG. **3** is a block diagram illustrating a system for maintaining and utilizing an indicator table in order to disambiguate file descriptors that are associated with files stored one media from those that are not, according to one embodiment of the present invention.

FIG. **4** is a block diagram illustrating a system for selectively intercepting system calls that access files of a specific type, according to one embodiment of the present invention.

FIGS. **5**A–B are flowcharts illustrating steps for performing an embodiment of the present invention.

FIGS. **6**A–B are flowcharts illustrating steps for performing another embodiment of the present invention.

FIGS. **7**A–D are flowcharts illustrating steps for performing another embodiment of the present invention.

FIGS. **8**A–D are flowcharts illustrating steps for performing another embodiment of the present invention.

## DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

### I. System Overview

FIG. **1** illustrates a system **100** for disambiguating file descriptors **102** according to one embodiment of the present invention. A computer memory **101** includes user address space **103** and operating system address space **105**. A process **107** executes in user address space **103**. Although FIG. **1** illustrates only a single process **107** executing in user address space **103**, it is to be understood that within a given computer memory **101**, multiple processes **107** can execute simultaneously.

In order to disambiguate file descriptors **102**, certain system calls **115** are intercepted. The interception of specific system calls **115** in order to disambiguate file descriptors **102** is described in detail below. In order to intercept system calls **115**, techniques known in the art are utilized to insert a system call wrapper **111** into the operating system **117**. In a preferred embodiment, a system call wrapper **111** is dynamically loaded into the operating system kernel **109**, while the kernel **109** is active. The system call wrapper **111** is preferably in the form of object code, the functional features of which are described in detail below. Preferably, a single system call wrapper **111** that includes all of the code object described below is loaded into the operating system kernel **109**. In alternative embodiments, multiple system calls wrappers **111** are loaded, each system call wrapper **111** including a subset of the object code.

Pointers **114** to system calls **115** are located in an operating system system call vector table **113**. It is to be understood that the term "system call vector table" as used herein denotes an area in operating system address space **105** in which there are stored the addresses of system calls. In the UNIX® operating system, this part of the operating system is called the "system call vector table," and that term is used in this specification. Other operating systems employ different terminology to denote the same system component. A system call vector table by any other name is still within the scope of the present invention.

A copy **116** is made of a pointer **114** to each system call **115** to be intercepted. These copies **116** of pointers **114** are preferably stored in operating system address space **105**, but in an alternative embodiment are stored in user address space **103**. Once the copies **116** have been made and saved, the pointers **114** in the system call vector table **113** to the system calls **115** to be intercepted are replaced with pointers **118** to the system call wrapper **111**, such that when a system call **115** to be intercepted is made, the system call wrapper **111** executes instead. In one embodiment of the present invention, this copying, storing, and replacing of pointers is performed by the system call wrapper **111**. In other embodiments, copying, storing, and replacing of pointers is performed by a pointer management module executing in either operating system address space **105** or user address space **103** as desired. The pointer management module can either be a stand alone program, or a component of a larger application program as desired.

Executing alternative code when a system call **115** is made comprises intercepting the system call **115**. The steps of inserting a system call wrapper **111** into the operating system **117**, making a copy **116** of an operating system pointer **114** to a system call **115**, and replacing the operating system pointer **114** with a pointer **118** to the system call wrapper **111** facilitate interception of a system call **115**. When a system call **115** to be intercepted is made, the operating system **117** uses the pointer **118** in the system call vector table **113** to the system call wrapper **111** to execute the system call wrapper **111**.

It is to be understood that in the present invention, not all system calls **115** are intercepted. Only pointers **114** to system calls **115** to be intercepted are replaced with pointers **118** to the system call wrapper **111**. Pointers **114** to system calls **115** which are not to be intercepted are not replaced. Thus, when a non-intercepted system call **115** is made, the system call **115** executes, not the system call wrapper **111**.

Preferably, a data structure for storing indicators **129** is inserted into the operating system **117**. In one embodiment, the data structure is an indicator table **127**, but in other embodiments other data structures are utilized, for example a linked list. In a preferred embodiment, the indicator table **127** (or other data structure) is dynamically loaded into the operating system kernel **109**, while the kernel **109** is active. In one alternative embodiment, the indicator table **127** is stored in user address space **103**. Regardless, the system call wrapper **111** maintains the indicator table **127** so that the indicator table **127** includes, for each file descriptor **102** that is associated with a specific file type, an indicator **129** of the association. The maintenance and use of the indicator table **127** is discussed in detail below.

Processes **107** execute in user address space **103** under control of the operating system **117**, and make system calls **115**. When a process makes a system call **115** that is to be intercepted, the system call wrapper **111** executes.

### II. Disambiguating Communication Channel File Descriptions

FIG. **2** illustrates a system **200** for maintaining and utilizing a table **127** of indicators **205** concerning communication channel file descriptors **201** in order to disambiguate file descriptors **201** that are associated with communication channels from file descriptors **102** that are not, according to one embodiment of the present invention.

It is to be understood that by the words "communication channel" it is meant a logical interface via which communication can be conducted. A communication channel is typically although not necessarily associated with both a network address and a port. Typically, separate communi-

cation channels must be present at each end of a communication session. A communication channel is sometimes denoted by the words "communication channel end" or "communication channel end point." Communication channels include but are not limited to sockets.

In the embodiment of FIG. **2**, system calls that establish a communication channel **203** are intercepted. Examples of system calls that establish a communication channel **203** are the UNIX® socket function and the UNIX® accept function. It is to be understood that the names of the system calls that establish a communication channel **203** vary from operating system **117** to operating system **117**. The present invention is not limited to any specific operating system **117**, or to any specific system call name. Some operating systems **117** include a single system call that establishes a communication channel **203**. Other operating systems **117** include more than one system call that establishes a communication channel **203**.

To prepare to intercept system calls that establish a communication channel **203**, internal operating system pointers **114** in the system call vector table **113** to such system calls **203** are copied. The copies of the pointers **116** may be stored in operating system address space **105** or in user address space **103**, as desired. The pointers **114** in the system call vector table **113** to system calls that establish a communication channel **203** are replaced with pointers **118** to the system call wrapper **111**, such that when the system calls **203** are made, the system call wrapper **111** is executed instead.

When a system call that establishes a communication channel **203** is made, the operating system **117** uses the pointer **118** in the system call vector table **113** to execute the system call wrapper **111**. The system call wrapper **111** first utilizes the saved copy of the pointer **116** to the system call **203** to make the system call **203**. The system call **203** executes, thereby establishing the communication channel. After having established the communication channel, the system call **203** returns a file descriptor that is associated with the established communication channel **201**. This file descriptor **201** is to be used by processes **107** in order to access the established communication channel. After the system call **203** terminates, the system call wrapper **111** stores (in the indicator table **127**) an indicator **205** that the file descriptor **201** returned by the system call **203** is associated with a communication channel.

In order to keep the indicator table **127** current, system calls **115** that create a copy of a file, a copy of a file descriptor **102**, or a copy of an operating system file descriptor **102** table are also intercepted. It is to be understood that a system call **115** that copies a file also copies a file descriptor **102**, because when a new file (the copy of the original file) is created, a new file descriptor **102** is also created, the new file descriptor **102** being associated with the new file.

To prepare to intercept system calls **115** that create a copy of a file, a copy of a file descriptor **102**, or a copy of an operating system file descriptor **102** table, copies **116** are made of internal operating system pointers **114** in the system call vector table **113** to such system calls **115**. The pointers **114** in the system call vector table **113** to these system calls **115** are replaced with pointers **118** to the system call wrapper **111**, such that when the system calls **115** are made, the system call wrapper **111** is executed instead.

Whenever any process **107** makes a system call **115** to copy a file, the system call wrapper **111** executes. First, the system call wrapper **111** checks the indicator table **127** to determine whether the file descriptor **102** associated with the file to be copied is associated with a communication channel. If so, the copy of the file, and hence the copy of its associated file descriptor **201**, will also be associated with a communication channel. The system call wrapper **111** utilizes the copy of the pointer **116** to execute the system call **115**. The system call **115** executes and creates a copy of the file, and also a copy of its associated file descriptor **201** (in an alternative embodiment, the system call wrapper **111** creates the copies itself, rather than making the system call **115**). After the system call **115** exits, the system call wrapper **111** stores an indicator **205** in the indicator table **127** that the file descriptor **201** associated with the copy of the file is associated with a communication channel. If the file to be copied is not associated with a communication channel, the system call wrapper **111** simply makes the system call **115** such that execution control returns to the calling process **107** after the system call **115** executes.

Some system calls **115** simply copy an existing file descriptor **102**, without copying its associated file. These system calls **115** are also intercepted. When a communication channel file descriptor **201** is copied, the system call wrapper **111** stores an indicator **205** in the indicator table **127** that the copy of the file descriptor **201** is associated with a communication channel.

System calls **115** that copy an entire file descriptor **102** table are also intercepted. For each file descriptor **102** in the file descriptor **102** table, the system call wrapper **111** checks the indicator table **127** to determine whether the file descriptor **102** is associated with a communication channel. The system call wrapper **111** then utilizes the copy of the pointer **116** to execute the system call **115**. The system call **115** executes and creates a copy of the file descriptor **102** table. After the system call **115** exits, the system call wrapper **111** stores, for each communication channel file descriptor **201** in the file descriptor **102** table, an indicator **205** that the created copy of the file descriptor **201** is associated with a communication channel.

In order to keep the indicator table **127** current, system calls **115** that delete a file descriptor **102** are also intercepted. Note that a system call **115** that deletes a file also deletes the associated descriptor **102** of the file. Thus, by the phrase "system calls **115** that delete a file descriptor **102**," it is meant both system calls **115** that delete a file descriptor **102** only, and system calls **115** that delete a file and its associated descriptor **102**.

Whenever a process **107** makes a system call **115** to delete a file descriptor **102**, the system call wrapper **111** executes instead. The system call wrapper **111** checks the indicator table **127** to determine whether the file descriptor **102** to be deleted is associated with a communication channel. If so, the system call wrapper **111** utilizes the copy of the pointer **116** to execute the system call **115**, which deletes the file descriptor **201** (in an alternative embodiment, the system call wrapper **111** deletes the file descriptor **201** itself, rather than making the system call **115**). After the system call **115** exits, the system call wrapper **111** deletes the indicator **205** in the indicator table **127** that the file descriptor **201** is associated with a communication channel. This is appropriate, because the file descriptor **201** no longer exists. If the file descriptor **102** to be deleted is not associated with a communication channel, the system call wrapper **111** simply makes the system call **115** such that execution control returns to the calling process **107** after the system call **115** executes.

Thus, system calls that establish a communication channel **203** are intercepted. When these system calls **203** are

made, the system call wrapper **111** executes and stores, in the indicator table **127**, an indicator **205** that the file descriptor **201** of the established communication channel is a communication channel file descriptor **201**. System calls **115** that copy or delete file descriptors **102** are also intercepted. If a file descriptor that is associated with a communication channel **201** is copied or deleted, the system call wrapper **111** updates the indicator table **127** appropriately. Thus, the indicator table **127** preferably includes an indicator **205** for every existing file descriptor that is associated with a communication channel **201**.

Because the indicator table **127** includes indicators **205** for file descriptors that are associated with communication channels **201**, the indicator table **127** can be utilized to determine whether or not a specific file descriptor **102** is associated with a communication channel. The indicator table **127** can be examined to determine if an indicator **205** concerning the specific file descriptor **102** is present. If so, the file descriptor **201** is associated with a communication channel. If no such indicator **205** is present, the file descriptor **102** is not associated with a communication channel.

In some operating systems **117**, every file descriptor **102** is either associated with a file stored on media or with a communication channel. In embodiments of the present invention that execute under such operating systems **117**, the indicator table **127** can be utilized to determine whether or not any specific file descriptor **102** is associated with a communication channel, and whether or not any specific file descriptor **102** is associated with a file stored on media. The indicator table **127** can be utilized to determine whether or not a file descriptor **102** is associated with a communication channel, as described above. Because file descriptors **102** that are not associated with communication channels are associated with files stored on media, the indicator table **127** can also be utilized to determine whether or not a specific file descriptor **102** is associated with a file stored on media. In order to so determine, the indicator table **127** is examined to determine if an indicator **205** concerning the specific file descriptor **102** is present. If not, the file descriptor **102** is associated with a file stored on media. If such an indicator **205** is present, the file descriptor **102** is not associated with a file stored on media.

### III. Disambigiuating File Descriptors Concerning Files Stored on Media

FIG. **3** illustrates a system **300** for maintaining and utilizing a table **127** of indicators **305** concerning file descriptors that are associated with files stored on media **301** in order to disambiguate file descriptors that are associated with files stored on media **301** from file descriptors **102** that are not, according to one embodiment of the present invention.

In the embodiment of FIG. **3**, system calls that establish a file stored on media **303** are intercepted. When a system call that establishes a file stored on media **303** is made, the operating system **117** uses the pointer **118** in the system call vector table **113** to execute the system call wrapper **111**. The system call wrapper **111** first utilizes the saved copy of the pointer **116** to the system call **303** to make the system call **303**. The system call **303** executes, thereby establishing the file stored on media. After having established the file stored on media, the system call **303** returns a file descriptor that is associated with the established file stored on media **301**. This file descriptor **301** is to be used by processes **107** in order to access the established file stored on media.

After the system call **303** terminates, the system call wrapper **111** stores (in the indicator table **127**) an indicator **305** that the file descriptor **301** returned by the system call **303** is associated with a file stored on media. Thus, whenever a system call that establishes a file stored on media **303** is made, the system call wrapper **111** executes and stores, in the indicator table **127**, an indicator **305** that the file descriptor **301** of the established file stored on media is associated with a file stored on media.

In order to keep the indicator table **127** complete, system calls **115** that create a copy of a file, a copy of a file descriptor **102**, or a copy of an operating system file descriptor **102** table are also intercepted, as in the embodiment of FIG. **2**. Additionally, in order to keep the indicator table **127** current, system calls **115** that delete a file descriptor **102** are intercepted, as in the embodiment of FIG. **2**. Thus, system calls **115** that copy or delete file descriptors **102** are intercepted. If a file descriptor that is associated with a file stored on media **301** is copied or deleted, the system call wrapper **111** updates the indicator table **127** appropriately. Therefore, the indicator table **127** preferably includes an indicator **305** for every existing file descriptor that is associated with a file stored on media **301**.

Because the indicator table **127** includes an indicator **305** for file descriptors that are associated with files stored on media **301**, the indicator table **127** can be utilized to determine whether or not a specific file descriptor **102** is associated with a file stored on media. The indicator table **127** can be examined to determine if an indicator **305** concerning the specific file descriptor **102** is present. If so, the file descriptor **301** is associated with a file stored on media. If no such indicator **305** is present, the filed descriptor **102** is not associated with a file stored on media.

As described above, in some operating systems **117**, every file descriptor **102** is either associated with a file stored on media or with a communication channel. In embodiments of the present invention that execute under such operating systems **117**, the indicator table **127** can be utilized to determine whether or not any specific file descriptor **102** is associated with a file stored on media, and whether or not any specific file descriptor **102** is associated with a communication channel. The indicator table **127** can be utilized to determine whether or not a file descriptor **102** is associated with a file stored on media, as described above. Because file descriptors **102** that are not associated with files stored on media are associated with communication channels, the indicator table **127** can also be utilized to determine whether or not a specific file descriptor **102** is associated with a communication channel. In order to so determine, the indicator table **127** is examined to determine if an indicator **305** concerning the specific file descriptor **102** is present. If not, the file descriptor **301** is associated with a communication channel. If such an indicator **305** is present, the file descriptor **102** is not associated with a communication channel.

It is to be understood that the present invention is not limited to utilizing indicators **205** concerning communication channel file descriptors **201** and indicators **305** concerning file descriptors associated with files stored on media **301** in order to disambiguate file descriptors **102**. Other embodiments of the present invention utilize the above described steps to maintain indicator tables **127** including indicators concerning file descriptors **102** associated with other file types (for example, file descriptors **102** associated with hardware devices and file descriptors **102** associated with system resources). It is to be understood further that the term "file type" can be defined as broadly or narrowly as desired. Files that are stored on media are an example of a broad file type. Narrower file types include files stored on media in specific directories, files with a specific attribute such as read only, and even a specific file (a file type of one).

In these alternative embodiments, the respective indicator tables **127** are examined to determine whether or not specific file descriptors **102** are associated with specific file types. In other embodiments, an indicator table **127** including indicators **129** concerning multiple file types (or multiple indicator tables **127** each concerning one or more types) is (are) maintained and examined to disambiguate file descriptors **102**. In some embodiments in which disambiguation concerns descriptors **102** of a narrow file type, when a system call **115** that establishes a file is intercepted, the system call wrapper **111** determines whether the established file is of the file type. For example, consider an embodiment in which file descriptors **102** that are associated with files stored on media in a specific directory are disambiguated from files descriptors that are associated with other files stored on media. All system calls that establish a file stored on media **303** are intercepted. The system call wrapper **111** determines if the file being established is to be stored in the specific directory. Only if so does the system call wrapper **111** store an indicator **129** that the file descriptor **102** is associated with the file type. System calls **115** that copy and delete file descriptors are also intercepted, and the table **127** is updated appropriately as files are copied to and deleted from the specific subdirectory.

## IV. Selective Interception of System Calls that Access Files of a Specific Type

FIG. **4** illustrates a system **400** for utilizing an indicator table **127** to selectively intercept system calls **115** that access files of a specific type, according to one embodiment of the present invention. An indicator table **127** including indicators **405** concerning file descriptors **102** associated with the specific file type is maintained. In one embodiment the file type is communication channels. In another embodiment the file type is files stored on media. In yet another embodiment, the file type is hardware devices. Still other embodiments include other file types as desired. Regardless, system calls **115** that establish files of the specific file type are intercepted, and indicators **405** concerning file descriptors **102** associated with the specific file type are stored in the indicator table **127**, in the manner described in the embodiment of FIG. **2** and in the embodiment of FIG. **3**. In order to keep the indicator table **127** complete and current, system calls **115** that make a copy of a file descriptor **102** and that delete a file descriptor **102** are also intercepted in the manner described in the embodiment of FIG. **2** and in the embodiment of FIG. **3**. Whenever a file descriptor **102** associated with the specific file type is copied or deleted, the indicator table is updated appropriately. Thus, the indicator table **127** preferably includes an indicator **405** for every file descriptor **102** associated with the specific file type.

The indicator table **127** is then used to facilitate selective interception of system calls **115** that access a file of the specific file type. System calls that access a file via a file descriptor **403** are intercepted. Examples of system calls that access a file via a file descriptor **403** are the UNIX® read function and the UNIX® write function. It is to be understood that the names of the system calls that access a file via a file descriptor **403** can vary from operating system **117** to operating system **117**. The present invention is not limited to any specific operating system **117**, or to any specific system call name.

To prepare to intercept system calls that access a file via a file descriptor **403**, a copy **116** is made of internal operating system pointers **114** in the system call vector table **113** to such system calls **403**. The pointers **114** in the system call vector table **113** to system calls that access a file via a file descriptor **403** are replaced with pointers **118** to the system call wrapper **111**, such that when the system calls **403** are made, the system call wrapper **111** is executed instead.

When a system call that accesses a file via a file descriptor **403** is made, the operating system **117** uses the pointer **118** in the system call vector table **113** to execute the system call wrapper **111**. The system call wrapper **111** examines the indicator table **127** to determine whether or not the file descriptor **102** is associated with the specific file type. If the file descriptor **102** is associated with the specific file type, the system call wrapper **115** continues to execute. If the file descriptor **102** is not associated with the specific file type, the system call **115** utilizes the saved copy of the pointer **116** to the system call **403** to make the system call **403**, such that when the system call **403** finishes executing, execution control returns to the calling process **107**.

Thus, system calls that access a file via a file descriptor **403** are selectively intercepted based on the file type. For example, suppose it is desirable only to intercept system calls that access communication channels **203**, but not to intercept system calls that access files stored on media **303**. When a system call that accesses a file via a file descriptor **403** is made (for example, a call to the read function), the system call wrapper **111** executes and examines the indicator table **127** to determine whether the file descriptor **102** that the system call **403** is attempting to access is associated with a communication channel. If so, the system call wrapper **111** proceeds to execute as desired. If the file descriptor **102** is not associated with a communication channel, the system call wrapper **111** makes the system call **115**, such that execution control is returned to the calling process after the system call **115** terminates. Of course, the present invention can also be used to selectively intercept system calls that access files stored on media, as well as any other specific file type.

In summary, the present invention facilitates the disambiguation of file descriptors associated with any file type. Such disambiguation of file descriptors allows the selective interception of system calls that access files of any specific file type via a file descriptor.

The execution of steps for performing various above described embodiments of the present invention are further illustrated by FIGS. **5A–8D**.

What is claimed is:

**1**. A method in a computer system for disambiguating file descriptors, the method comprising:

intercepting system calls that establish a file descriptor;

storing at least one indicator of a file type associated with an established file descriptor;

intercepting system calls that create a copy of at least one file descriptor;

storing at least one indicator concerning a created copy of a file descriptor; and

upon an attempt to access a file via a file descriptor, examining at least one stored indicator to determine with what file type the file descriptor is associated.

**2**. The method of claim **1** wherein intercepting a system call that creates a copy of at least one file descriptor comprises:

intercepting a system call that creates a copy of a file descriptor table.

**3**. A method in a computer system for disambiguating file descriptors, the method comprising:

intercepting system calls that establish a communication channel;

storing at least one indicator that a file descriptor established by an intercepted system call is associated with a communication channel;

intercepting system calls that utilize a file descriptor to access a file, wherein intercepting a system call that utilizes a file descriptor to access a file comprises replacing a pointer to the system call with a pointer to alternative object code, such that making the system call causes the alternative object code to execute;

examining at least one stored indicator to determine with what file type the file descriptor of an intercepted system is associated; and

in response to a determination that the file descriptor is associated with a file stored on media, performing one of:

1) allowing the alternative object code to continue to execute; or

2) terminating execution of the alternative object code, and requesting execution of the system call.

**4**. A method in a computer system for disambiguating file descriptors, the method comprising:

intercepting system calls that establish a communication channel;

storing at least one indicator that a file descriptor established by an intercepted system call is associated with a communication channel;

intercepting system calls that utilize a file descriptor to access a file, wherein intercepting a system call that utilizes a file descriptor to access a file comprises replacing a pointer to the system call with a pointer to alternative object code, such that making the system call causes the alternative object code to execute;

examining at least one stored indicator to determine with what file type the file descriptor of an intercepted system is associated; and

in response to a determination that the file descriptor is not associated with a communication channel, performing one of:

1) allowing the alternative object code to continue to execute; or

2) terminating execution of the alternative object code, and requesting execution of the system call.

**5**. A method in a computer system for disambiguating file descriptors, the method comprising:

intercepting system calls that establish a communication channel;

storing at least one indicator that a file descriptor established by an intercepted system call is associated with a communication channel;

intercepting system calls that create a copy of at least one file descriptor;

storing at least one indicator concerning a created copy of a file descriptor; and

examining at least one stored indicator to determine with what file type a file descriptor is associated.

**6**. The method of claim **5** further comprising:

where a copied file descriptor is associated with a communication channel, storing an indicator that a created copy of the file descriptor is associated with a communication channel.

**7**. The method of claim **5** wherein:

intercepting a system call that creates a copy of at least one file descriptor comprises intercepting a system call that creates a copy of a file descriptor table.

**8**. A method in a computer system for disambiguating file descriptors, the method comprising:

intercepting system calls that establish a file stored on media;

storing at least one indicator that a file descriptor established by an intercepted system call is associated with a file stored on media, wherein storing an indicator that an established file descriptor is associated with a file stored on media further comprises storing the indicator in a table; and

examining at least one stored indicator to determine with what file type a file descriptor is associated.

**9**. A method in a computer system for disambiguating file descriptors, the method comprising:

intercepting system calls that establish a file stored on media;

storing at least one indicator that a file descriptor established by an intercepted system call is associated with a file stored on media; and

examining at least one stored indicator to determine with what file type a file descriptor is associated, wherein examining comprises, intercepting system calls that utilize a file descriptor to access a file, and examining at least one stored indicator to determine with what file type the file descriptor of an intercepted system call is associated, wherein intercepting a system call that utilizes a file descriptor to access a file comprises replacing a pointer to the system call with a pointer to alternative object code, such that making the system call causes the alternative object code to execute; and

in response to a determination that the file descriptor is associated with a file stored on media, performing one of:

1) allowing the alternative object code to continue to execute; or

2) terminating execution of the alternative object code, and requesting execution of the system call.

**10**. A method in a computer system for disambiguating file descriptors, the method comprising:

intercepting system calls that establish a file stored on media;

storing at least one indicator that a file descriptor established by an intercepted system call is associated with a file stored on media;

intercepting system calls that utilize a file descriptor to access a file, wherein intercepting a system call that utilizes a file descriptor to access a file comprises replacing a pointer to the system call with a pointer to alternative object code, such that making the system call causes the alternative object code to execute;

examining at least one stored indicator to determine with what file type the file descriptor of an intercepted system call is associated; and

in response to a determination that the file descriptor is not associated with a communication channel, performing one of:

1) allowing the alternative object code to continue to execute; or

2) terminating execution of the alternative object code, and requesting execution of the system call.

**11**. A method in a computer system for disambiguating file descriptors, the method comprising:

intercepting system calls that establish a file stored on media;

intercepting system calls that create a copy of at least one file descriptor;

storing at least one indicator that a file descriptor established by an intercepted system call is associated with a file stored on media;

storing at least one indicator concerning a created copy of a file descriptor; and

examining at least one stored indicator to determine with what file type a file descriptor is associated.

**12**. The method of claim **11** further comprising:

where a copied file descriptor is associated with a communication channel, storing an indicator that a created copy of the file descriptor is associated with a communication channel.

**13**. The method of claim **11** wherein:

intercepting a system call that creates a copy of at least one file descriptor comprises intercepting a system call that creates a copy of a file descriptor table.

**14**. A computer program product for disambiguating file descriptors, the computer program product comprising:

program code for intercepting system calls that establish a file descriptor;

program code for storing at least one indicator of a file type associated with an established file descriptor;

program code for, upon an attempt to access a file via a file descriptor, examining at least one stored indicator to determine with what file type the file descriptor is associated;

program code for intercepting system calls that create a copy of at least one file descriptor;

program code for storing at least one indicator concerning a created copy of a file descriptor; and

a computer readable medium on which the program codes are stored.

**15**. A computer program product for disambiguating file descriptors, the computer program product comprising:

program code for intercepting system calls that establish a communication channel;

program code for storing at least one indicator that a file descriptor established by an intercepted system call is associated with a communication channel;

program code for examining at least one stored indicator to determine with what file type a file descriptor is associated;

program code for intercepting system calls that utilize a file descriptor to access a file;

program code for examining at least one stored indicator to determine with what file type the file descriptor of an intercepted system is associated;

program code for replacing a pointer to the system call with a pointer to alternative object code, such that making the system call causes the alternative object code to execute;

program code for, in response to a determination that the file descriptor is associated with a file stored on media, performing one of:

1) allowing the alternative object code to continue to execute; or

2) terminating execution of the alternative object code, and requesting execution of the system call; and

a computer readable medium on which the program codes are stored.

**16**. A computer program product for disambiguating file descriptors, the computer program product comprising:

program code for intercepting system calls that establish a communication channel;

program code for storing at least one indicator that a file descriptor established by an intercepted system call is associated with a communication channel;

program code for examining at least one stored indicator to determine with what file type a file descriptor is associated;

program code for intercepting system calls that utilize a file descriptor to access a file;

program code for examining at least one stored indicator to determine with what file type the file descriptor of an intercepted system is associated;

program code for replacing a pointer to the system call with a pointer to alternative object code, such that making the system call causes the alternative object code to execute;

program code for, in response to a determination that the file descriptor is not associated with a communication channel, performing one of:

1) allowing the alternative object code to continue to execute; or

2) terminating execution of the alternative object code, and requesting execution of the system call; and

a computer readable medium on which the program codes are stored.

**17**. A computer program product for disambiguating file descriptors, the computer program product comprising:

program code for intercepting system calls that establish a communication channel;

program code for storing at least one indicator that a file descriptor established by an intercepted system call is associated with a communication channel;

program code for examining at least one stored indicator to determine with what file type a file descriptor is associated;

program code for, intercepting system calls that create a copy of at least one file descriptor;

program code for storing at least one indicator concerning a created copy of a file descriptor; and

a computer readable medium on which the program codes are stored.

**18**. The computer program product of claim **17** further comprising:

program code for, where a copied file descriptor is associated with a communication channel, storing an indicator that a created copy of the file descriptor is associated with a communication channel.

**19**. A computer program product for disambiguating file descriptors, the computer program product comprising:

program code for intercepting system calls that establish a file stored on media;

program code for storing at least one indicator that a file descriptor established by an intercepted system call is associated with a file stored on media;

program code for examining at least one stored indicator to determine with what file type a file descriptor is associated;

program code for intercepting system calls that utilize a file descriptor to access a file;

program code for examining at least one stored indicator to determine with what file type the file descriptor of an intercepted system call is associated;

program code for replacing a pointer to the system call with a pointer to alternative object code, such that making the system call causes the alternative object code to execute;

program code for, in response to a determination that the file descriptor is associated with a file stored on media, performing one of:

1) allowing the alternative object code to continue to execute; or

2) terminating execution of the alternative object code, and requesting execution of the system call; and

a computer readable medium on which the program codes are stored.

**20**. A computer program product for disambiguating file descriptors, the computer program product comprising:

program code for intercepting system calls that establish a file stored on media;

program code for storing at least one indicator that a file descriptor established by an intercepted system call is associated with a file stored on media;

program code for examining at least one stored indicator to determine with what file type a file descriptor is associated;

program code for intercepting system calls that utilize a file descriptor to access a file;

program code for examining at least one stored indicator to determine with what file type the file descriptor of an intercepted system call is associated;

program code for replacing a pointer to the system call with a pointer to alternative object code, such that making the system call causes the alternative object code to execute;

program code for, in response to a determination that the file descriptor is not associated with a communication channel, performing one of:

1) allowing the alternative object code to continue to execute; or

2) terminating execution of the alternative object code, and requesting execution of the system call; and

a computer readable medium on which the program codes are stored.

**21**. A computer program product for disambiguating file descriptors, the computer program product comprising:

program code for intercepting system calls that establish a file stored on media;

program code for storing at least one indicator that a file descriptor established by an intercepted system call is associated with a file stored on media;

program code for examining at least one stored indicator to determine with what file type a file descriptor is associated;

program code for intercepting system calls that create a copy of at least one file descriptor;

program code for storing at least one indicator concerning a created copy of a file descriptor; and

a computer readable medium on which the program codes are stored.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

# CERTIFICATE OF CORRECTION

PATENT NO. : 6,560,613 B1 Page 1 of 1
DATED : May 6, 2003
INVENTOR(S) : Snorri Gylfason, Xun Wilson Huang and Rosen Sharma

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Title page,
Item [56], OTHER PUBLICATIONS, please delete the duplicate listing of "Rusling, D. A., Linux Processes, [online], [retrieved on Dec. 7, 1999]. Retrieved from the Internet: <URL: http://www.cebaf.gov/~saw/linux/tlk-html/node45.html>" and replace with -- Rusling, D. A., Indentifiers, [online], [retrieved on Dec. 7, 1999]. Retrieved from the Internet: <URL: http://www.cebaf.gov/~saw/linux/tlk-html/node46.html> --

Signed and Sealed this

Twenty-sixth Day of August, 2003

JAMES E. ROGAN
*Director of the United States Patent and Trademark Office*